Final Report on NASA Contract NAS8-28055

Tradeoffs in Manipulator Structure and Control

Part I

SUMMARY

by

Daniel E. Whitney
Wayne J. Book
Octavio Maizza-Neto

(NASA-CR-120493) TRADEOFFS IN MANIPULATOR STRUCTURE AND CONTROL. PART 1: SUMMARY Final Report (Massachusetts Inst. of Tech.) 4 p HC $4.00 CSCL 20K

N74-35306

Unclas
G3/32 51846

Prepared by **Department of Mechanical Engineering**
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

For **George C. Marshall Space Flight Center, NASA**
Marshall Space Flight Center, Alabama 35812

August 31, 1974

pt 4 - 015- 51157

Tradeoffs in Manipulator Structure and Control

Part I: SUMMARY

A study of various aspects of manipulator design and control has been conducted, focusing on the interaction of the structure's flexible dynamics and the dynamics of the joint control systems. The results are presented in Parts II, III, and IV which are summarized below.

Part II: Modeling, Design, and Control of Flexible Manipulator Arms.

Distributed and lumped parameter models of the various arm components were combined via transfer matrices and numerical techniques were used to derive frequency domain information on the complete arm model. This modeling technique was used in a design context for a specific arm under construction. In this use it indicated the sizing required of the structural members and suggested that more general conclusions on structural requirements for adequate rigidity could be reached. Additional study indicated that for the assumed common form of control a rule of thumb limiting the arm bandwidth to one-half the lowest locked actuator natural frequency was quite accurate for the link, joint combinations explored. This rule replaces more conservative estimates of rigidity requirements.

The requirements for strength (stress limitations) and rigidity were expressed nondimensionally in terms of the pertinent arm performance specifications. Analysis of single link arms based on these requirements indicated the relative significance of strength and stiffness constraints for regions of a three dimensional space of arm specifications. The results indicate practical application for improved manipulator control schemes.

Part III. Modal Analysis and Control of Flexible Manipulator Arms.

In order to study more advanced control schemes and to include nonlinear effects, additional study was undertaken. A modal approach is used throughout this section of the work for obtaining the mathematical model and control techniques applied. The arm model is represented mathematically by a state space description defined in terms of joint angles and mode amplitudes obtained from truncation on the distributed system and includes the nonlinear dynamic effects. The work concentrated on the planar motion of a two link two joint arm.

The problem of controlling the system was examined via the linearized model and using a regulator type of control. Three basic techniques were used for this purpose: pole location with gains obtained from the rigid system with interjoint feedbacks, the Simon Mitter algorithm for pole allocation and sensitivity analysis with respect to parameter variations. An improvement in arm bandwidth was obtained that could replace the simpler designs explored in Part II.

The ideal geometric arm configuration was found to be a function of payload sizes and programmed tasks.

The controlled system was examined under constant gains and using the nonlinear model for simulations following a time varying state trajectory. The procedure presented in this work is general and can be implemented to be used in more specific arm designs.

Part IV: Flexible Manipulator Analysis Program.

The computer programs (Flexible Manipulator Analysis Programs or FMAP) that were used in Part II are documented in this section. Complete instructions on using FMAP and examples of various features of the package are included. The Rancho Anthropomorphic Arm (RAM) of the Marshall Spaceflight Center is modelled as an exercise demonstrating the modelling procedure. Suggestions for implementing FMAP on a new computer system are given as well as a listing of the program.